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STATE OF CALIFORNIA

DEPARTMENT OF TRANSPORTATION
DIVISION OF NEW TECHNOLOGY,
MATERIALS AND RESEARCH

SALTMARSH RESTORATION, REHABILITATION, AND CREATION TECHNIQUES FOR CALTRANS CONSTRUCTION PROJECTS

Final Report #FHWA/CA/TL-93/12A

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16. Abstract

Highway construction projects along the California coast can potentially damage adjacent saltwater marshes causing a loss of saltmarsh values. Normally, the California Department of Transportation (Caltrans) tries to avoid these losses by moving highway alignments or other techniques. Occasionally, saltmarsh losses are unavoidable necessitating marsh restoration projects to replace lost saltmarsh values. Considerable information is available from research completed on saltmarsh mitigation, but much of this research has been conducted in States along the East Coast and Gulf of Mexico. Much less specific information is available for California. In this study, we investigated saltmarsh hydrodynamic processes, soil development, vegetation establishment, monitoring requirements, spatial requirements, construction techniques and storm water treatment. The purpose of the investigation was to determine information needs and methods available to conduct effective saltmarsh mitigation projects. A series of interim reports were prepared including an annotated bibliography of saltmarsh literature, a research needs manual and four guidance manuals for coastal saltmarsh mitigation in California.

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CONVERSION FACTORS

English to Metric System (SI) of Measurement

Quality	English Unit	Multiply By	To Get Metric Equivalent
Length	inches (in) or (")	25.40 .02540	millimetres (mm) metres (m)
	feet (ft) or (')	.3048	metres (m)
	miles (mi)	1.609	kilometres (km)
Area	square inches (in^2) square feet (ft^2) acres	6.432×10^{-4} .09290 .4047	square metres (m^2) square metres (m^2) hectares (ha)
Volume	gallons (gal) cubic feet (ft^3) cubic yards (yd^3)	3.785 .02832 .7646	litre (l) cubic metres (m^3) cubic metres (m^3)
Volume/Time (Flow)	cubic feet per second (ft^3/s)	28.317	litres per second (l/s)
	gallons per minute (gal/min)	.06309	litres per second (l/s)
Mass	pounds (lb)	.4536	kilograms (kg)
Velocity	miles per hour (mph) feet per second (fps)	.4470 .3048	metres per second (m/s) metres per second (m/s)
Acceleration	feet per second squared (ft/s^2)	.3048	metres per second squared (m/s^2)
	acceleration due to force of gravity (G)	9.807	metres per second squared (m/s^2)
Density	(lb/ft^3)	16.02	kilograms per cubic metre (kg/m^3)
Force	pounds (lb) kips (1000 lb)	4.448 4448	newtons (N) newtons (N)
Thermal Energy	British thermal unit (BTU)	1055	joules (J)
Mechanical Energy	foot-pounds (ft-lb) foot-kips (ft-k)	1.356 1356	joules (J) joules (J)
Bending Moment or Torque	inch-pounds (in-lb) foot-pounds (ft-lb)	.1130 1.356	newton-metres (Nm) newton-metres (Nm)
Pressure	pounds per square inch (psi) pounds per square foot (psf)	6895 47.88	pascals (Pa) pascals (Pa)
Plane Angle	degrees (°)	0.0175	radians (rad)
Temperature	degrees fahrenheit (°F)	$\frac{°F - 32}{1.8} = °C$	degrees celsius (°C)
Concentration	parts per million (ppm)	1	milligrams per kilogram (mg/kg)

NOTICE

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INTRODUCTION

Historically the extent of California salt marshes has never been great. Except for large marshes along the Southern California coast, San Francisco Bay and Humboldt Bay, salt marshes in California are essentially confined to the mouths of rivers as they enter the ocean. Much of this habitat has been lost, especially in the larger embayments due to filling and dredging and other activities associated with human habitation. Currently, to protect what remains of the California salt marsh habitat, construction or other activities that have an impact on salt marsh habitat require mitigation in the form of restoration, reconstruction or rehabilitation. However, the ways in which natural marshes develop and maintain existence are only understood in general terms. Therefore, a much more thorough understanding of marsh dynamics is essential to insure that marsh mitigation efforts are successful.

CONCLUSIONS AND RECOMMENDATIONS

This research found that with the current state of knowledge, it is possible to provide sufficient guidance in planning, constructing and monitoring salt marsh mitigation projects to help insure that projects are successful in the long-term. Project goals compatible with the available site are probably most important in determining the overall success of a project and they need to be carefully considered during the planning and design phase of a marsh creation project. These goals effect all decisions concerning the project. Additionally, it was found that monitoring is essential to determine if the project goals are being met; it should continue throughout the life of the project. Further, overall size of the marsh site is a significant factor in marsh stability. Small, isolated marshes with only a minimum amount of channel branching (first or second order channels) are relatively unstable; larger marsh projects have a better chance of success and provide more regionally significant saltmarsh values. Unfortunately, the minimum size required for a marsh to be self sustaining has not been determined.

The following specific conclusions and recommendations summarize the findings of this research. They represent the status of saltmarsh mitigation efforts in California and present the minimum essential information necessary to improve overall saltmarsh mitigation success.

1. Significant portions of the literature on salt marsh restoration are specifically relevant to portions of the East Coast and Gulf of Mexico. Comparatively less information is available for salt marsh restoration projects in California.

2. With the current state of knowledge, it is possible to provide sufficient guidance in planning, constructing and monitoring salt marsh creation and restoration projects to help insure long-term successful projects. Among the critical planning and implementing requirements for a successful project are:

A. Initial site assessment to establish site suitability for a marsh creation project is essential to insure adequate information available during the planning and design process.

B. A thorough, consistent and pertinent monitoring program conducted throughout the life of the project is essential to the health and long term viability of the marsh creation project.

C. A set of attainable project goals is the most important factor to be considered during the planning and design phase of a mitigation project. These goals will essentially define aspects such as marsh elevations, tidal circulation and the need to modify soil and water conditions.

D. The selection of construction techniques that consider the unique and sensitive environment to insure that wetland soils are not destroyed during the construction process.

E. A plan for long term operations and maintenance that includes post construction monitoring and plant and site rehabilitation is essential. The planned post construction monitoring and maintenance should continue until managers are assured that project goals are met and the marsh is self sustaining.

3. Complete information is lacking to develop a full understanding of the dynamics of salt marsh ecosystems. Consequently, the long term success of salt marsh restoration, rehabilitation and replacement projects designed to establish certain wetland values is variable and not readily predictable. Among areas that require additional research to improve our understanding of mitigation techniques are:

A. Hydrodynamic Processes: Determination of the optimal marsh surface area to channel order and stability relationships is required, especially the viability of small isolated saltmarsh development projects and the stability of lower order channels.

B. Soil Development: Determination of methods and techniques that can be used to modify the chemical and biological characteristics of existing and imported soils to support the growth of various types of marsh plants. Additionally, the time and conditions required for existing and imported soils to become similar to natural marsh soils needs to be determined.

C. Vegetation Establishment: Determination of propagation methods, planting techniques and maintenance requirements for different habitats, species and climates are required for California salt marshes.

D. Monitoring Procedures: Determination of specific parameters that can be used to plan the construction and predict the success of marsh development throughout the life of a salt marsh mitigation project.

IMPLEMENTATION

A copy of the interim and final reports of this research will be sent to each coastal Highway District. The reports include the four geographically oriented Guidance Manuals, the Research Needs Manual and the Annotated Bibliography. As additional research refines methods, Guidance Manuals will be updated.

BACKGROUND

Over 30 million people live in California, the vast majority of whom live in or near population centers of Southern California and the San Francisco Bay. These people work and play in close association with the coast of California and for many, their quality of life is associated with access to and recreational opportunities derived from the coast and ocean. This large population requires constant improvements in infra-structure, including transportation projects, to continue providing a meaningful quality of life in the area. Construction of these projects often leads to direct and indirect impacts on the coastal habitat and consequently, salt marsh wetlands in California have been significantly reduced in amount and quality over time.

The conflict that arises between the needs of many people living in an urban environment and the desire to maintain the coastal environment and quality of life that attracts those people to the area has resulted in attempts to mitigate for the loss of wetlands by restoration of destroyed habitat, the rehabilitation of degraded habitat, or the creation of new habitat. Because previous land use decisions have established highway alignments in the coastal zone, traffic improvement projects often have impacts on the few remaining coastal marshes. Consequently, the California Department of Transportation (Caltrans) must mitigate for the loss of coastal saltmarsh habitat due to highway improvement projects by replacing, enhancing or constructing new salt marshes.

Mitigation for loss of saltmarsh wetlands is developed by agreements with environmental agencies. They generally require the Department to construct substantial wetland acreage as replacement for lost habitat and to provide a long term guarantee that the lost wetland values will be replaced by the proposed mitigation. However, the present knowledge of saltmarsh dynamics is not sufficiently well understood to permit engineering plans and landscape design that always meet the required guarantees. The purpose of this research was to determine what is

METHOD

The research program was conducted by the Department of Civil Engineering, University of California at Davis under contract to the California Department of Transportation, Division of New Technology, Materials and Research. The research procedure consisted primarily of a literature study, interviews with professionals knowledgeable in California salt marsh habitat formation, restoration and reconstruction, and field reviews of salt marsh mitigation projects with individuals from the sponsoring and constructing agencies.

RESULTS AND DISCUSSION

Research results were concentrated in the areas of: California saltmarsh development, saltmarsh hydrodynamic processes, salt marsh soils and soil development, typical salt marsh vegetation and vegetation establishment, spatial requirements (including buffer zones), construction techniques and equipment, and monitoring requirements and methods. Additionally, information on storm water treatment by salt marshes was investigated. From these investigations, a series of interim reports were prepared including an annotated bibliography, a report on research needs and four geographically oriented, saltmarsh restoration guidance manuals.

The annotated bibliography consists of saltmarsh references utilized during the research needs investigation and the development of the guidance manuals. The references, with particular emphasis on California salt marshes, included all publicly available saltmarsh literature and as much unpublished research as was available. In all 423 books, reports and articles were reviewed for this bibliography. The earliest article was written in 1927 with the latest in 1991. The bibliography is indexed by author and by keyword and organized chronologically.

NATURAL DEVELOPMENT:

The research needs manual summarizes available information on saltmarsh development and mitigation and makes recommendations for additional research. In general, it was found that natural saltmarsh formation begins when suspended sediments, carried by tidal currents, settle out of the water in areas protected from wave and wind action. Where the rate of sediment accretion exceeds resuspension, the deposited sediment level rises until the surface is exposed for a portion of the tidal cycle forming a mud flat. The mud flat is stabilized by algal growth and possibly through some desiccation due to exposure of the surface to the atmosphere (Krone, 1985). The rising surface and algae mass slow the tidal currents further decreasing the size and amount of sediment that can be suspended in the water column. As a result, sediment continues to be deposited and as the surface of the mud flat continues to rise, the ebbing tidal flow begins to cut drainage patterns through the sediment (Pestrong, 1965).

As sediment continues to be deposited, low marsh vascular plants can become established. These plants have adapted to habitats that include daily periods of tidal flooding and saline soils. Pacific cordgrass (*Spartina foliosa*) occurs at the lowest elevations along the Southern and Central California coast, while seaside arrowgrass (*Triglochin maritima*) dominates from San Francisco Bay northward (Woodhouse, 1979). Pickleweed (*Salicornia virginica*) can be the dominate vascular plant at lower elevations along the entire coast in some situations. In some locations other less common plants dominate the lower intertidal region. Whichever plants are established, once established, the presence of these vascular plants greatly increases sedimentation and the rate of marsh plain development (Krone, 1982). As the marsh elevation rises, other plants compete with lower intertidal vegetation and other distinct plant communities develop. Various crustaceans, insects and other invertebrates utilize the many habitats available in the expanding marsh. These invertebrates serve as an important food source for many birds, fish and mammals which are attracted to the marsh by the presence of food and habitat.

Further, it was determined that California marsh development is dynamic. They are subject to significant physical and chemical changes depending upon the surrounding environment. Marshes found in bays and estuaries are usually continuously open to the sea and have relatively stable water quality conditions. Other marshes formed in the mouths of rivers or coastal lagoons may be seasonally isolated and consequently water quality fluctuates from saline to brackish depending on conditions. Marshes are also subject to periodic changes due to large storm floods, which may alter the marsh profile, channel configuration and vegetation distribution. And, more recently, almost every coastal saltmarsh in California has been affected by human activity. Significant among these activities are upstream damming which deprives marshes of sediment for regeneration and decreases the volume of large cleaning floods. Also significant are: the construction of roads and levees which change marsh hydrodynamics, the increased erosion from adjacent land development, diking and filling, and the discharge of contaminated water from industrial and residential sources.

Successful saltmarsh mitigation projects must specifically address the natural processes that affect the development of salt marshes including hydrodynamics, geomorphology and biological development. The amount that any of these processes can be manipulated to create conditions favorable for a saltmarsh mitigation project is affected by the specifics of the site and the limitations of these processes as they relate to the site. A marsh creation or restoration project will have a greater probability of success where existing conditions already favor the natural development of salt marshes.

HYDRODYNAMICS:

Marsh hydrodynamics has a direct impact on marsh geometry and is a major factor in determining sedimentation and erosion rates, plant propagation and water quality. Flow patterns in the marsh control the transport of sediment, detritus, seeds and propagules. The tidal ebb and flow control the rate of sedimentation and the buildup of excess nutrients. Much of the success of marsh mitigation projects depends on the interaction of tidal and fresh water flow in the marsh area. For example, the stability of lower order marsh sloughs is directly related to the volume of water that is carried during the tidal cycle. If the slough is too large, excess sedimentation will impact development of marsh channels, if too small, excess erosion will impact the marsh surface.

Because of the impact that hydrodynamic processes have on marshes, design methods are required to predict flow, sedimentation rates and channel requirements. However, the hydrodynamic processes for saltwater marshes are not well understood. Additional information needs include: understanding the physics of flow and sedimentation rates in marshes, development of predictive models based on an improved understanding of marsh hydrodynamics and development of post construction monitoring techniques to insure hydrodynamic processes are developing as designed.

GEOMORPHOLOGY:

When hydrodynamic processes are combined with marsh geomorphology and spatial requirements, they define the potential marsh habitats that can be supported. Aspects of geomorphology such as marsh orientation with respect to adjacent bodies of water, percentage of open water, upland and tidal habitats, and overall marsh size affect the quality of marsh habitat.

As an example, marshes oriented with a long axis perpendicular to a bay or estuary would normally have one, or at most a few long drainage channels, with side branches into the marsh and relatively shallow slopes. Conversely, marshes oriented with a long axis parallel to the body of water would have multiple short drainage channels and relatively steeper slopes.

Additionally, overall size of the marsh site is a significant factor in marsh stability. Small, isolated marshes with only first or second order channels are relatively unstable having channels that shift throughout the marsh. They will normally require maintenance to exist as designed and constructed. Larger marshes with fourth or fifth order channels are, overall, much more stable than smaller sites and can normally be self sustaining. It is often more appropriate to plan a small mitigation project within a larger established marsh farther away from the site of the original disturbance than to attempt to produce a self sustaining small mitigation project on site. Further, larger marshes usually have areas that provide refuge for marsh animals during very high tides and larger buffer zones allowing for marsh migration and isolation from anthropomorphic effects. Unfortunately, the minimum size required for a marsh to be self sustaining has not been determined.

HYDRODYNAMICS/GEOMORPHOLOGY INTERACTIONS:

Soil development and vegetation establishment are both dependent upon successful establishment of correct marsh hydrodynamic processes and geomorphology. Natural saltmarsh soils are fine grained soils that are water logged for at least some of the tidal cycle, are saline and have a high organic content. Lower marsh soils are also anaerobic below the soil surface. The lack of oxygen in these soils gives rise to an environment where chemicals will exist in their reduced state. The vegetation associated with salt marshes has adapted to survival under these conditions, developing methods to excrete excess salt and to survive when partially submerged for some period of each day.

During saltmarsh mitigation projects, marsh soil development has been attempted in at least two different ways. The first method relies on sediment transport and more mimics natural marsh formation. Native soil is excavated six or more inches below the planned profile and natural sedimentation is encouraged. However, this method is time consuming and does not work well in establishing middle and high marsh soils. The supply of natural sediment is often inadequate because of anthropomorphic changes in the upstream watershed and it may be of poor quality.

The second method consists of modifying the site either by altering existing soils on site or importing soils. Altering existing soils by modification of upland or improving degraded marsh soils is difficult. These soils normally lack sufficient fine grained material, do not have a high organic content and are often not chemically stabile. Alternately, dredge material may be imported to provide a soil substrate. These normally anaerobic soils may undergo significant changes in soil characteristics as they are exposed to the atmosphere requiring some time to stabilize before vegetation can be established and may result in very saline soils if used for upper and middle marsh soils.

Soil parameters that were found to be critical and predictive of successful soil development included: soil source, soil gradation, pH, salinity, degree of aeration, nutrient and organic matter content, and pollutant content. All soils at a mitigation site will need to be modified in some manner. However, the methods required to modify soils successfully are not well developed.

BIOLOGICAL DEVELOPMENT:

Saltmarsh plant species are adapted to specific conditions of elevation (relation to tidal prism), period of inundation and salinity in the marsh and to specific climatic conditions along California's 1000 mile coastline. Salt marshes have been divided into several distinct elevation zones by several investigators to account for the observed distribution of plants (Hinde, 1954; Vogl, 1966; Mahall and Park, 1976). However, Zedler and Nordby (1986) considered the distribution of plants in the Tijuana Estuary to be a continuum with each species having an elevation at which it had it's maximum occurrence. But, in any case, specific species occur most frequently at elevations that provide the most optimum conditions for survival.

Vegetation supports animal species by producing food, cover and nesting material. To a large extent, specific plant associations determine the functional values available in a marsh habitat. Failed saltmarsh revegetation projects can usually be associated with either improper soil conditions, hydrodynamic conditions or both. Occasionally, marsh restoration plantings have failed because of other factors such as destruction by herbaceous predators or vandalism, or because the plants were not adapted to the area where they were planted.

The distribution and occurrence of saltmarsh plant species is dependent not only on tidal elevation but by geography as well. Species occur in geographical ranges along the California coast and may occupy different elevations in marshes depending upon where in the species range the specimen was growing. Further, closely related species often do not have the same habitat requirements. As an example, *Spartina densiflora*, an exotic saltmarsh grass found in Humboldt Bay was introduced into San Francisco Bay to occupy the same niche as *S. foliosa*, however, *S. densiflora* occurs at a tidal elevation higher than *S. foliosa* and is competing with *Salicornia sp*. in the lower middle marsh reaches instead of establishing in the lower marsh. Only *Spartina foliosa* existed as a monotypic stand at elevations below 2.3 feet above mean sea level in the Tijuana Estuary (Zedler, 1977). Therefore, an understanding of the habitat requirements for species of concern is essential to successful complete marsh restoration projects.

Also essential to successful plant establishment is an understanding of plant establishment criteria for different areas of the State. Differences among the many marshes in California, including factors previously discussed means that considerable information needs to be developed and planting guidelines need to be determined that are specific to the varied habitats found in California. Unfortunately, only *S. foliosa* has been commonly planted in past projects resulting in it's being the only species with significant documentation. Regional differences have not been adequately investigated or documented. Information is available, however, from San Francisco Bay (Harvey, *et al*., 1983) and Southern California (Zedler, 1984).

MONITORING PLANS:

Another essential element in marsh restoration, especially given the state of current knowledge, is a well planned monitoring program. Development of a monitoring program must be based on an assessment of initial project goals and begin during initial planning and continue until the project goals are met. Many marsh restoration experts believe that monitoring should continue for at least five years after project completion (Josselyn and Buchholz, 1984; Harvey, et al., 1983; Zedler, 1988). The monitoring program must be adapted to the specific marsh habitat. The specific parameters that will be monitored need to be chosen based on what the marsh restoration project is attempting to accomplish. However, general parameters such as pH, redox potential, salinity, dissolved oxygen and plant and animal distribution studies are usually included in all monitoring programs and provide information on the health of the marsh project. Monitoring general parameter often points to more intensive or specific study needs. As a minimum, a general monitoring protocol is needed including the identification of key monitoring parameters to effectively indicate the health of the new marsh.

GUIDANCE MANUALS:

Based on the findings of the research needs investigations, four Guidance Manuals were developed to address current saltmarsh restoration along the California coast. The manuals incorporate information on marsh restoration, rehabilitation and creation techniques to help Caltrans personnel plan, construct and monitor saltmarsh mitigation projects. Each manual was written to describe general and specific information for four specific regions of coastal wetlands. The regions were selected because of similarities among the marshes within the regions. The four regions selected were Northern California, which includes the area from Bodega Bay north to the Oregon border; Central California, which includes the area south of

Bodega Bay along the coast to Point Conception; Southern California, which includes the area south of Point Conception; and San Francisco Bay. Each manual is organized into a series of chapters dealing with a set of marsh restoration procedures. The chapters include: Regional Description, Site Assessment, Monitoring, Planning, Design, Construction, and Operations and Maintenance. Each chapter, except the regional description, begins with a checklist of activities that should be conducted, followed by background material pertinent to the items found in the checklist.

This study looked at various aspects of marsh mitigation procedures. All aspects need additional research, but sufficient information is currently available which will allow most projects to be successful depending upon the definition of success. Most significant, almost immediate overall improvement in most marsh mitigation project performance could be obtained if realistic project goals were set based on an understanding of the possible potential habitats for the area and an effective monitoring and follow-up program were implemented as part of the project plan. Ultimately, the most important goal of any saltmarsh mitigation project is to establish conditions that will result in a self sustaining, mature marsh habitat. However, replacing all functional marsh values, such as soil chemistry, species diversity and other characteristics which are identical to a natural, mature marsh are possible only with time.

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